Predicting the Next Location:
A Recurrent Model with Spatial and Temporal Contexts

Qiang Liu, Shu Wu, Liang Wang, Tieniu Tan., AAAI. 2016.

Problem Formulation

- Task is to predict where a user will go next at a specific time t.
- P : set of users
  - $p_u \in R^d$: latent vectors of user u
- Q : set of locations
  - $q_u \in R^d$: latent vectors of location v
- $v = \{x_v, y_v\}$
- $Q^U = \{Q^{u_1}, Q^{u_2}, \dots\}$
- $Q^u = \{q^u_{t_1}, q^u_{t_2}, \dots\}$

Recurrent Neural Networks

$$\mathbf{h}^u_{t_k} = f\left(\mathbf{M}\mathbf{q}^u_{t_k} + \mathbf{C}\mathbf{h}^u_{t_{k-1}}\right)$$

- $h^u_{t_k}$: representation of user u at time t_k
- C : recurrent connection of the previous status propagating sequential signals
- M : transition matrix
- f : sigmoid

RNN with Temporal Context

$$\mathbf{h}_t^u = f\left(\sum_{q_{t_i}^u \in Q^u, t-w<t_i<t} \mathbf{T}_{t-t_i}\mathbf{q}_{t_i}^u + \mathbf{C}\mathbf{h}_{t-w}^u\right)$$

- w : width of time window
- T_{t-t_i}: time-specific transition matrix (current time t)

Spatial Temporal Recurrent Neural Networks

$$\mathbf{h}^u_{t,q^u_t} = f\left(\sum_{q^u_{t_i} \in Q^u, t-\hat{w}<t_i<t} \mathbf{S}_{q^u_t - q^u_{t_i}} \mathbf{T}_{t-t_i} \mathbf{q}^u_{t_i} + \mathbf{C}\mathbf{h}^u_{t-\hat{w}, q^u_{t-\hat{w}}}\right)$$

- $S_{q^u_t - q^u_{t_i}}$: distance-specific transition matrix
- geographical distance

$$q^u_t - q^u_{t_i} := \left\| x^u_t - x^u_{t_i}, y^u_t - y^u_{t_i} \right\|_2$$

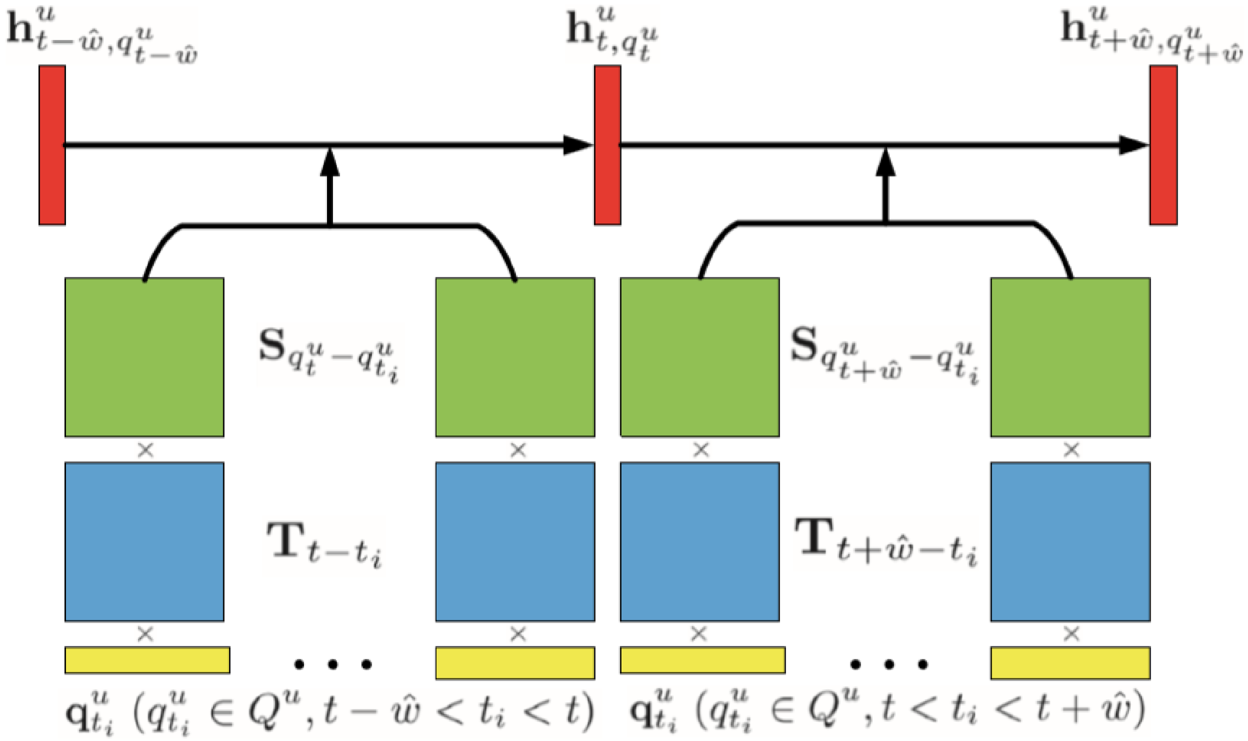
- Not exist the location user u visits at time $t - w$ in the visiting history Q^u
  - Approximate value $\widehat{w}$: the most closed value to w

ST-RNN (cont'd)

- Prediction

$$o_{u,t,v} = (\mathbf{h}^u_{t,q_v} + \mathbf{p}_u)^T \mathbf{q}_v$$

  - p_u : permanent presentation of user u



Linear Interpolation for Transition Matrices

- Data sparsity problem
  - Partition time interval and geographical distance into discrete bins
  - Transition matrices can be calculated via a linear interpolation

$$\mathbf{T}_{t_d} = \frac{\left[\mathbf{T}_{L(t_d)}(U(t_d) - t_d) + \mathbf{T}_{U(t_d)}(t_d - L(t_d))\right]}{\left[(U(t_d) - t_d) + (t_d - L(t_d))\right]} \, ,$$

$$\mathbf{S}_{l_d} = \frac{\left[\mathbf{S}_{L(l_d)}(U(l_d) - l_d) + \mathbf{S}_{U(l_d)}(l_d - L(l_d))\right]}{\left[(U(l_d) - l_d) + (l_d - L(l_d))\right]} \, ,$$

Parameter Inference

- User prefers a selected location than a negative one

$$p(u, t, v \succ v') = g(o_{u,t,v} - o_{u,t,v'})$$

  - v' : negative location sample
  - $g(x) = 1/(1 + e^{-x})$

- Negative log likelihood

$$J = \sum \ln(1 + e^{-(o_{u,t,v} - o_{u,t,v'})}) + \frac{\lambda}{2} \|\Theta\|^2$$

Experimental Settings

- Gowalla

[user]	[check-in time]	[latitude]	[longitude]	[location id]
196514	2010-07-24T13:45:06Z	53.3648119	-2.2723465833	145064
196514	2010-07-24T13:44:58Z	53.360511233	-2.276369017	1275991
196514	2010-07-24T13:44:46Z	53.3653895945	-2.2754087046	376497
196514	2010-07-24T13:44:38Z	53.3663709833	-2.2700764333	98503
196514	2010-07-24T13:44:26Z	53.3674087524	-2.2783813477	1043431
196514	2010-07-24T13:44:08Z	53.3675663377	-2.278631763	881734
196514	2010-07-24T13:43:18Z	53.3679640626	-2.2792943689	207763
196514	2010-07-24T13:41:10Z	53.364905	-2.270824	1042822

- Recall@k
- F1-Score@k
- Mean Average Prediction (MAP)
- ROC curve (AUC)